Movements of transplanted lingcod, *Ophiodon elongatus*, determined by ultrasonic telemetry

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Lingcod, *Ophiodon elongatus*, have formed an important component of commercial and recreational fisheries from Alaska to California. In the center of their range, however, in Puget Sound, Washington, and in the Strait of Georgia, British Columbia, Canada, lingcod stocks are currently depressed. For example, annual commercial catches in the Strait of Georgia declined from a high of 3300 metric tons (t) in 1944 to 80 t in 1989, probably owing to overfishing (Ketchen et al., 1983; Richards and Yamanaka, 1992). In 1990, the commercial fishery was closed; however, a restrictive recreational catch is still permitted. Similar declines in central Puget Sound led to a complete fishery closure between 1978 and 1982, followed by a small recreational fishery (Buckley et al., 1984).

Because of the value of the lingcod fishery, there is considerable interest in rebuilding these stocks. This paper describes a feasibility experiment for one approach to enhance natural stock rebuilding. Abundance is currently average or above average for lingcod stocks in offshore areas of the British Columbia coast (Richards and Yamanaka, 1992). Lingcod could be transplanted from these areas into the Strait of Georgia. Such an experiment was conducted by Buckley et al. (1984) in Puget Sound. They found that transplanted young-of-the-year lingcod (10–20 cm) were caught in the area 2 and 3 years after release. However, most transplanted adult lingcod left the area and migrated towards their capture site. Our experiment involved transplanting juvenile lingcod (age 2–3 yr) and tracking their movement in the new area through ultrasonic telemetry.

Ultrasonic telemetry has been used successfully on a number of marine fish species (Holland et al., 1985, 1990; Quinn et al., 1989; Clark and Green, 1990; Ruggerone et al., 1990; Matthews et al., 1990). Unlike conventional tags, ultrasonic tags allow continuous monitoring of fish movements. They are usually limited, however, to small sample sizes and short time periods because of cost and labour constraints. Ultrasonic telemetry was useful for this study because precise positions could be obtained for individual fish.

Matthews (1992) conducted a previous ultrasonic telemetry study on lingcod. In addition to tracking six stationary lingcod, she displaced five adult male lingcod a short distance (maximum 2.8 km) from their capture site. Four of these lingcod returned to their exact capture sites within 60 hours. Thus, she demonstrated that adult male lingcod were capable of homing over short distances. She concluded that transplants of adult male lingcod would likely be unsuccessful, given this tendency to home.

We addressed two issues left unanswered by Matthews (1992). In particular, we designed an experiment with juvenile rather than adult lingcod and we displaced these fish a relatively long distance (250 km). We determined whether lingcod remained at the transplant site over a period of approximately one month. Based on previous studies, we hypothesized that homing lingcod would leave the transplant area within a few days and exhibit directional movements towards the capture site. We compared the movements of transplanted lingcod with similar-size control lingcod caught, tagged, and released in the study area.

Methods

The experiment was conducted off the east coast of Vancouver Island, British Columbia (Fig. 1). The 12 × 4 km study area was chosen because it contained shallow reefs typical of lingcod habitat (Ketchen et al., 1983). The area was conveniently marked by navigational aids and separated from small islands to the north and east by a 300-m deep channel. A commercial fishery existed here historically, and recent SCUBA and recreational fishing activities confirmed the presence of a small resident lingcod population.

Experimental lingcod were collected at the end of September 1991 from Queen Charlotte Strait, about 250 km northwest of the study area (Fig. 1). They were held for 5–34 days before being tagged and released. Prior to tagging, lingcod were immobilized in an anaesthetic bath (MS222, tricaine methane sulphonate). Tags were then anchored through the dorsal musculature adjacent to the dorsal fin by means of two self-locking nylon ties (Holland et al., 1985). Tagged lingcod were held overnight to assess condition; only healthy-appearing

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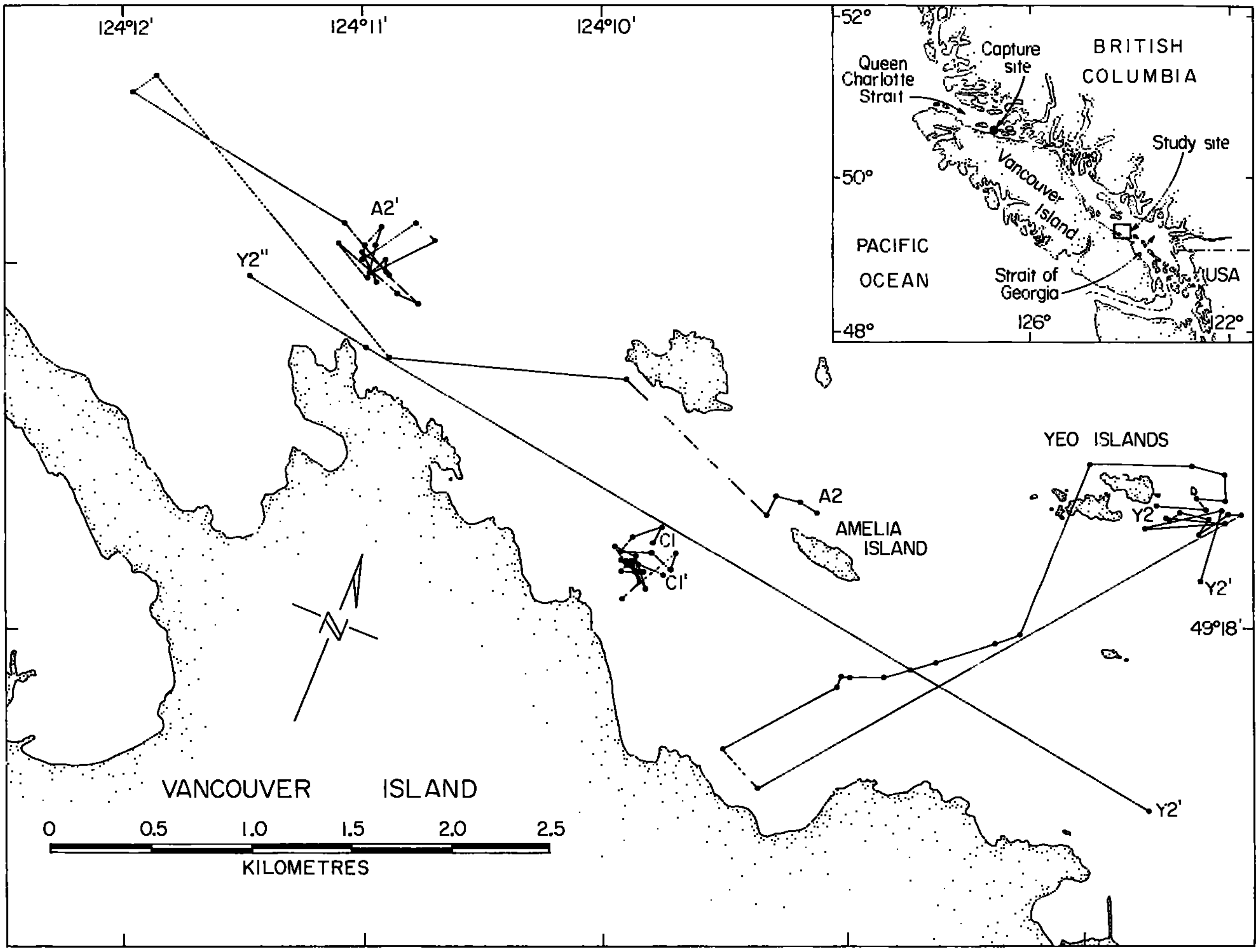

Figure 1

Location of the study area in the Strait of Georgia, British Columbia, and typical tracks of transient (fish Y2), resident (fish A2), and control (fish C1) groups of lingcod. The release site is indicated by the fish number and the prime symbol gives the last observed position. Fish Y2 left the study area, returned at position Y2', and was last observed at position Y2". A "." indicates each recorded position.

fish were used for the experiment. Experimental lingcod were released at one of two sites in the study area, either Amelia or Yeo Island (Fig. 1). Control lingcod were collected within the study area, held for 1–2 days, and released at their capture site.

Transmitters (Vemco Ltd., Armdale, Nova Scotia, Canada B3L 4J4) of two types were used, varying in battery life and size. A V3-5HI transmitter (16 × 95 mm) had one of four frequencies (60.00 Hz, 65.54 Hz, 69.00 Hz, 76.80 Hz) and six pulse rates. It weighed 34.5 g (in air) and had an expected battery life of 31 days. The smaller V2B-2L transmitter (8 × 38 mm) used identical frequencies but higher pulse rates. It weighed 11.5 g (in air) and had an expected battery life of 12 days. On average, fish weights were 40 times greater than the weight of the V3-5HI tag and 228 times greater than the weight of the V2B-2L tag (Table 1). Lingcod tagged with a V3-5HI transmitter could be detected at distances from 0 to 1 km, depending on the complexity of the habitat in which the fish was located. Detection range of the V2B-2L transmitter was approximately half that of the V3-5HI transmitter.

Two different strategies were used for tracking. A few fish were tracked continuously over a 2–3 day period; position of the fish was recorded at 1-hour intervals if the fish was stationary and at intervals as frequent as 10 minutes for rapidly moving fish. Other lingcod were located at least three times during a 12-hour tracking period and individually tracked for 30 minutes to 1 hour. We assumed that a lingcod left the study area if it could not be found after a search of the entire study area, provided that its transmitter was active (based on the manufacturer's estimate of battery life). We continued to search for each lingcod throughout the active life of its tag.

Table 1

Fish number, sex, fork length, weight, weight ratio of fish/tag (in air), release date, number of positions recorded, days between release and last recorded position, observed distance travelled, mean daily movement rate, and number (n) of 24-hour periods used to calculate mean daily movement rates for transient, resident, and control groups of ultrasonic-tagged lingcod.

Group	number	sex	length (cm)	weight (kg)	ratio fish/tag	release date	no. of positions	no. of days	distance (km)	movement rate km/d	n
Transient	A1	F	62	2.4	70	Oct 15	27	4	16.2	0.71	4
	A4	M	58	1.9	55	Oct 28	31	7	16.1	2.67	4
	[1]A5	M	53	1.4	275	Nov 4	7	2	3.2		
	Y1	M	54	1.5	44	Oct 7	68	4	12.5	1.79	4
	Y2	M	53	1.4	41	Oct 9	48	19	16.8	0.89	7
	Y6	M	51	1.4	41	Oct 23	15	7	9.2		
	Y7	F	52	1.3	38	Oct 28	11	2	5.1		
Resident	A2	M	52	1.3	38	Oct 18	41	24	8.1	0.61	6
	A3	F	48	1.1	32	Oct 23	24	28	6.0	0.74	7
	[1]A6	F	47	1.0	196	Nov 4	4	8	6.8		
	Y3	M	51	1.1	32	Oct 11	83	21	18.2	0.53	14
	Y4	F	46	0.7	20	Oct 14	64	21	17.4	0.56	12
	Y5	F	50	1.2	35	Oct 18	57	25	28.9	1.47	12
Control	C1	F	50	1.0	29	Oct 30	38	50	5.3	0.06	8
	[1]C2	M	49	1.1	216	Nov 1	19	27	0.7	0.06	7
	[1]C3	F	51	1.2	235	Nov 9	18	40	0.7	0.03	3
	[1]C4	M	49	1.1	216	Nov 9	16	34	0.6	0.03	3

[1] V2B–2L tag.

Results

Approximately 120 hours of daylight and 170 hours of nighttime lingcod tracking were conducted between 7 October and 23 December 1991 (Table 1). Seven experimental fish were released at Yeo Island (fish Y1-Y7) and six experimental fish at Amelia Island (fish A1–A6). There were an additional four control fish (fish C1–C4). Based on size, most tagged lingcod were estimated to be sexually immature and 2–3 years of age. Lingcod from this area mature over a size range of 50–62 cm for males and 60–67 cm for females (Richards et al., 1990). The largest male and female lingcod used in the study had lengths of 58 and 62 cm, respectively.

Seven of the 13 experimental lingcod left the study area at least 7 days prior to their transmitter expiry dates (Table 1). We termed these lingcod as "transients" and the remaining experimental lingcod as "residents." Resident and control lingcod could be detected in the study area until their transmitter expiry dates. With the exception of fish Y2, transient lingcod were last observed 2–7 days after release. By contrast, most resident lingcod could be located in the study area after 28 days. Control fish were recorded after even longer periods. For example, fish C1 (V3–5HI tag) was observed after 50 days. Similarly, fish C3 (V2B–2L tag) was observed after 40 days. All the control fish were located in shallow water (depth of approximately 20 m) and maintained relatively constant positions over the course of the study.

The amount of time spent in the holding tank did not appear to affect the tendency of experimental lingcod to leave or remain in the study area. Lingcod in transient and resident groups did not differ significantly in the number of days held before release (Wilcoxon rank sum test, $P>0.10$). However, fish length ($P<0.05$) and weight ($P<0.01$) did differ significantly between transient and resident groups of lingcod (Wilcoxon rank sum test). Although sample size was too small to consider sex or transmitter size effects, both sexes and transmitter sizes were represented in each experimental group.

In general, individual tracks were similar for lingcod in the transient group and in the resident group. For example, Fish Y2 (transient) was released at the south side of Yeo Island, moved counter clockwise around Yeo Island, travelled southwest to Vancouver Island, and then returned to the release site in 5 days (Fig. 1). Fish Y2 remained within 0.5 km of the release site over the next 2 days where it was observed by SCUBA divers. For the next 10 days, fish Y2 could not be detected in the study area. It was then found south of Yeo Island, moved 7 km west, and left the study area 19 days after release. Fish A2 (resident) was released at the north side of Amelia Island, moved in a westerly direction for 5 days, turned east, and then remained within a 0.3 km^2 area for 17 days, after which the tag battery expired. All four control fish remained within 0.4 km^2 of their capture-release site over the entire tracking period.

Transient lingcod were apparently more active than resident lingcod, and control lingcod moved little. An analysis of variance on the ranked movement rate data for the experimental lingcod indicated that rates differed significantly among fish within a group ($P<0.001$) and, furthermore, that rates differed significantly between fish in transient and resident groups ($P<0.001$). Similarly, movement rates differed significantly between experimental and control groups of lingcod ($P<0.001$). Mean (±SE) movement rates were 4.9±0.5 m/min, 1.8±0.2 m/min, and 0.3±0.2 m/min, respectively, for transient, resident, and control groups of lingcod. Movement rate was also related to fish size. For the experimental lingcod, rank correlation coefficients between mean movement rate and fish length (0.69) and weight (0.60) were significant ($P<0.05$). Thus, fish size may determine movement patterns, which in turn determine the tendency of experimental lingcod to leave or remain in the study area.

We calculated the total (horizontal) distance travelled by each lingcod (Table 1) as the sum of the distances between sequential observations of fish position. This measurement obviously depends on the number of positions recorded for a fish during each tracking period. Furthermore, the number of positions recorded was highly variable, because of continuous observations for some fish. We computed daily movement rates (km/d) to ensure meaningful comparisons among fish. These rates were calculated from distances between estimated positions at 24-hour intervals for fish with three or more sequential daily position observations. As demonstrated for the raw movement data, daily movement rates were significantly greater for transient fish than for resident fish (Wilcoxon rank sum test, $P<0.05$), and for resident fish than for control fish (Wilcoxon rank sum test, $P<0.001$). Mean (±SE) daily movement rates were 1.42±0.24 km/d ($n=19$), 0.80±0.13 km/d ($n=51$), and 0.05±0.01 km/d ($n=21$) for transient, resident, and control groups of lingcod, respectively.

Continuous observations for four experimental fish were sufficiently long to examine diel activity patterns. We determined the distance travelled between estimated positions at sequential 2-hour periods (Fig. 2). By late-October, the study area was experiencing only 8 hours of daylight. Lingcod travelled the greatest distances at night (Fig. 2). Movement rates for these fish averaged 2.1±0.3 m/min ($n=58$) during the night (1600–0800 hours) and 0.7±0.1 m/min ($n=26$) during the day (0800–1600 hours).

Discussion

Movements of lingcod transplanted 250 km from their normal habitat were related to fish size. The larger fish tended to disperse from the study site within a few days of release. These results corroborate the findings of Buckley et al. (1984); when lingcod are transplanted over large distances, the smaller fish are more likely to remain in the new area.

The tendency for larger experimental lingcod to leave the study area may be related to the onset of sexual maturity. Lingcod spawn in the Strait of Georgia between December and March (Low and Beamish, 1978). Lingcod selected for the transplant were all smaller than the size at 50% maturity. However, sexual maturity in lingcod can occur over a wide size range (Richards et al., 1990). For example, all experimental male lingcod and one transient female lingcod were larger than the size at 20% maturity. Thus, some of the recorded movements could be associated with selection of spawning (nest guarding) sites.

Ultrasonic tags provide short-term information on fish behaviour. Experimental lingcod could be followed for at most 28 days (Table 1) and we can not discount the possibility that resident lingcod left the study area after the end of the experiment. Furthermore, tran-

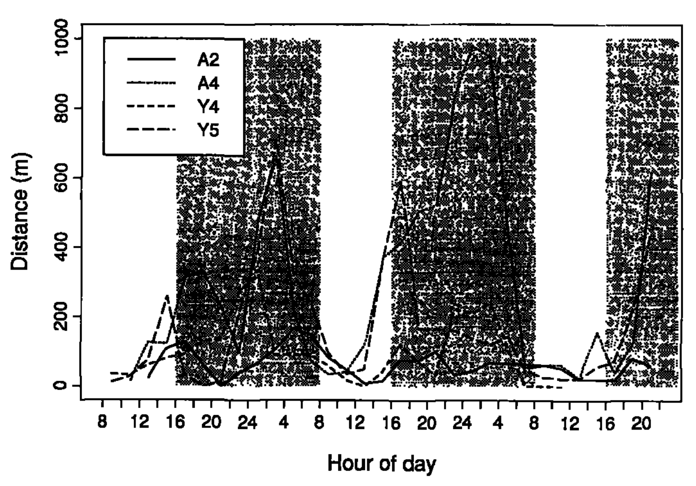

Figure 2

Distances travelled over 2-hour intervals by four lingcod observed continuously for 48–60 hours. Distances are shown corresponding to the interval midpoint. The shaded rectangles indicate periods of darkness.

sient lingcod may have become resident just outside the boundaries of the study area or returned at a later date. Fish Y2, for example, was apparently absent from the study area for 10 days before returning (Fig. 1). Conventional tagging studies are required to address these long-term issues. However, conventional tagging studies suffer from other problems. For example, the lack of fishing effort in the area due to seasonal closures would reduce the probability of tag recapture, and a minimum size limit (65 cm) would impose a size-selectivity on the recaptured fish.

Our measurements of lingcod movement rate were comparable to those reported by Matthews (1992). She observed movement rates of 1.17 km/d for displaced male lingcod, intermediate to the rates of 1.42 km/d and 0.80 km/d that we computed for lingcod in transient and resident groups, respectively. Furthermore, our estimate of nocturnal (1600–0800 h) movement rate was 2.1 m/min, identical to the rate that Matthews (1992) measured between 2400–0600 hours. The control lingcod in our study remained within the maximum home range size of 0.4 km^2 recorded by Matthews (1992).

It was not possible for us to determine whether lingcod moved toward their capture site after leaving the study area. Homing has been documented for adult lingcod (Hart, 1943; Cass et al., 1983; Matthews, 1992), but other factors undoubtedly affect fish movement. For example, the prevailing current in the Strait of Georgia flows to the northwest owing to land masses and prevailing winds from the southeast (Thomson, 1981). Hart (1943) observed from tag returns that most lingcod released in the Strait of Georgia moved in a northwesterly direction.

The purpose of this study was to determine whether stocking with juvenile lingcod could promote natural stock rebuilding. Because 6 of the 13 displaced fish did remain within the 12 × 4 km study area while their tags were active (28 days), restocking with juvenile lingcod is a potential enhancement tool. For transplanted fish to contribute to the spawning stock, they must remain in the new area and survive there until reproduction (spawning/nest guarding) is complete. Annual natural mortality rates for lingcod are 24% (Schnute et al., 1989). Mortality rates due to sport fishing and marine mammal predation may be higher (Collicutt and Shardlow, 1989; Olesiuk et al., 1990; Smith et al., 1990). To compensate for these mortalities, the number of age 2–3 year lingcod transplanted must be at least two to three times the number required to achieve a target spawning biomass one year later. A harvest of this magnitude could be detrimental to the donor stock. Until the depleted stock is re-established, the enhanced area should be closed to lingcod retention, and if possible, to all fishing activities. Hook and release mortality is not known but could decrease survivorship if fishing pressure is intense.

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Literature cited

Buckley, R., G. Hueckel, B. Benson, S. Quinnell, and M. Canfield.
1984. Enhancement research on lingcod *Ophiodon elongatus* in Puget Sound. Wash. Dept. Fish. Prog. Rep. 216, 93 p.

Cass, A. J., M. S. Smith, I. Barber, and K. Rinhofer.
1983. A summary of lingcod tagging studies conducted in 1978 by the Pacific Biological Station. Can. Data Rep. Fish. Aquat. Sci. 417, 283 p.

Clark, D. S., and J. M. Green.
1990. Activity and movement patterns of juvenile Atlantic cod, *Gadus morhua*, in Conception Bay, Newfoundland, as determined by sonic telemetry. Can. J. Zool. 68:1434–1442.

Collicutt L. D., and T. F. Shardlow.
1989. Strait of Georgia sport fishery creel survey statistics for salmon and groundfish, 1989. Can. MS Rep. Fish. Aquat. Sci. 2087, 75 p.

Hart, J. L.
1943. Migration of lingcod. Fish. Res. Board Can. Pac. Prog. Rep. 57:3–7.

Holland, K. N., R. W. Brill, S. Ferguson, R. Chang, and R. Yost.
1985. A small vessel technique for tracking pelagic fish. Mar. Fish. Rev. 47:26–32.

Holland, K. N., R. W. Brill, and R. K. C. Chang.
1990. Horizontal and vertical movements of yellowfin and bigeye tuna associated with fish aggregating devices. Fish. Bull. 88:493–507.

Ketchen, K. S., N. Bourne, and T. H. Butler.
1983. History and present status of fisheries for marine fishes and invertebrates in the Strait of Georgia, British Columbia. Can. J. Fish. Aquat. Sci. 40:1095–1119.

Low, C. J., and R. J. Beamish.
1978. A study of the nesting behavior of lingcod (*Ophiodon elongatus*) in the Strait of Georgia, British Columbia. Fish. Mar. Serv. Tech. Rep. 843, 27 p.

Matthews, K. R.
1992. A telemetric study of the home ranges and homing routes of lingcod *Ophiodon elongatus* on shallow rocky reefs off Vancouver Island, British Columbia. Fish. Bull. 90:784–790.

Matthews, K. R., T. P. Quinn, and B. S. Miller.
1990. Use of ultrasonic transmitters to track demersal rockfish movements on shallow rocky reefs. Am. Fish. Soc. Symp. 7:375–379.

Olesiuk, P. F., M. A. Bigg, G. M. Ellis, S. J. Crockford and R. Wigen.
1990. An assessment of the feeding habits of harbour seals (*Phoca vitulina*) in the Strait of Georgia, British Columbia, based on scat analysis. Can. Tech. Rep. Fish. Aquat. Sci. 1730, 135 p.

Quinn, T. P., B. A. Terhart, and C. Groot.
1989. Migratory orientation and vertical movements of homing adult sockeye salmon, *Oncorhynchus nerka*, in coastal waters. Anim. Behav. 37:587–599.

Richards, L. J., J. T. Schnute, and C. M. Hand.
1990. A multivariate maturity model with a comparative analysis of three lingcod (*Ophiodon elongatus*) stocks. Can. J. Fish. Aquat. Sci. 47:948–959.

Richards, L. J., and K. L. Yamanaka.
1992. Lingcod. *In* B. M. Leaman (ed.), Groundfish stock assessments for the west coast of Canada in 1991 and recommended yield options for 1992, p 23–56. Can. Tech. Rep. Fish. Aquat. Sci. 1866, 304 p.

Ruggerone, G. T., T. P. Quinn, I. A. McGregor, and T. D. Wilkinson.
1990. Horizontal and vertical movements of adult steelhead trout, *Oncorhynchus mykiss*, in the Dean and Fisher channels, British Columbia. Can. J. Fish. Aquat. Sci. 47:1963–1969.

Schnute, J. T., L. J. Richards, and A. J. Cass.
1989. Fish survival and recruitment: investigations based on a size-structured model. Can. J. Fish. Aquat. Sci. 46:743–769.

Smith, B. D., G. A. McFarlane, and A. J. Cass.
1990. Movements and mortality of tagged male and female lingcod in the Strait of Georgia, British Columbia. Trans. Am. Fish. Soc. 119:813–824.

Thomson, R. E.
1981. Oceanography of the British Columbia coast. Can. Spec. Publ. Fish. Aquat. Sci. 56, 291 p.